METHODS OF RECOVERY

SALT FROM SEA WATER

Solar evaporation is the only method now used for producing salt from sea water on a commercial scale, and even this is feasible in only a relatively small number of localities. Primarily, there must be sufficient evaporation and space available to produce a crop of salt large enough to handle economically. Of equal importance is the proximity of large industrial consumers that depend on low-cost salt with minimum freight charges. The California salt industry and the Pacific Coast chlorine-caustic industry in particular are mutually interdependent. Neither without the other could have achieved its present state of development.

California Practice. As primitive man knew, the production of salt by the evaporation of sea water is a simple operation. The commercial production of pure salt free from calcium and magnesium salts, however, requires a considerable degree of skill. Crude sea salt produced in California today contains at least 99 percent sodium chloride.

The process is essentially fractional crystallization. Sea water passes first through a series of outer or concentrating ponds where it is brought to saturation with respect to sodium chloride, and the less soluble salts are precipitated. The final concentrating pond is called the pickle or "lime" pond, and saturated brine is called pickle. To this point evaporation has reduced the volume of pickle to about 10 percent of the volume of sea water taken in. Next, pickle is run into a separate group of ponds called crystallizing ponds where continuing evaporation causes salt to form. In order to avoid the precipitation of the very soluble magnesium salts, the concentration of the liquor in the ponds is kept at a specific gravity of 29° to 30° Be by withdrawing mother liquor or bittern and replacing it with fresh pickle. The bittern may or may not be sold to chemical plants for the recovery of additional chemicals.

It will be recalled from the discussion of the precipitation of sea salts in an earlier section of this report that there is an overlapping of the crystallizing ranges of gypsum, salt, and the bittern salts. Some gypsum continues to crystallize in the range of maximum salt crystallization, and similarly the first traces of the bittern salts come down with the sodium chloride. Therefore the precipitation of neither gypsum nor bittern salts in the crystallizing ponds can be entirely prevented.

Concentrating ponds have natural mud bottoms and are formed by levees built of nearly impervious mud. Pond bottoms must be naturally water tight because no economical way of sealing leaking ponds is known. As far as possible concentrating ponds are located between the high and low tide marks so that the intake can be by means of tidal gates to minimize pumping. As the brine becomes more concentrated through evaporation it is pumped from one pond to the next. Individual ponds are shallow to allow maximum evaporation and 100 to 500 acres or even larger in size.

Typically the concentrating ponds are arranged in a series of about 10. Almost always terrain features make it necessary to divide the concentrating area into small units, but there is believed to be a fundamental reason also. It has been calculated that in a single pond of area equivalent to that of a series of smaller ponds it would take about 20 years for the brine to reach saturation. One reason is that the evaporation rate decreases with increasing concentration and at saturation is only 40 percent of that of distilled water.

Crystallizing ponds are rectangular in shape and have flat bottoms prepared by scraping and rolling. Pumps and ditches are provided for rapid filling and draining. The ratio of concentrating ponds to crystallizing ponds ranges from 15 to 1 to the theoretical minimum of 10 to 1. In size they range from 10 acres or less to 50 or 60 acres, depending on the type of harvesting equipment used.

Evaporation takes place only during the spring, summer, and fall. During the winter the concentrating ponds remain full, and at some plants the crystallizing ponds are left full also. Rain water tends to lie on the surface of strong brine and does not mix with it unless the wind is strong.

Crystallizing ponds are harvested once a year and are drained one at a time shortly before the harvesting equipment is ready to enter it. All California plants

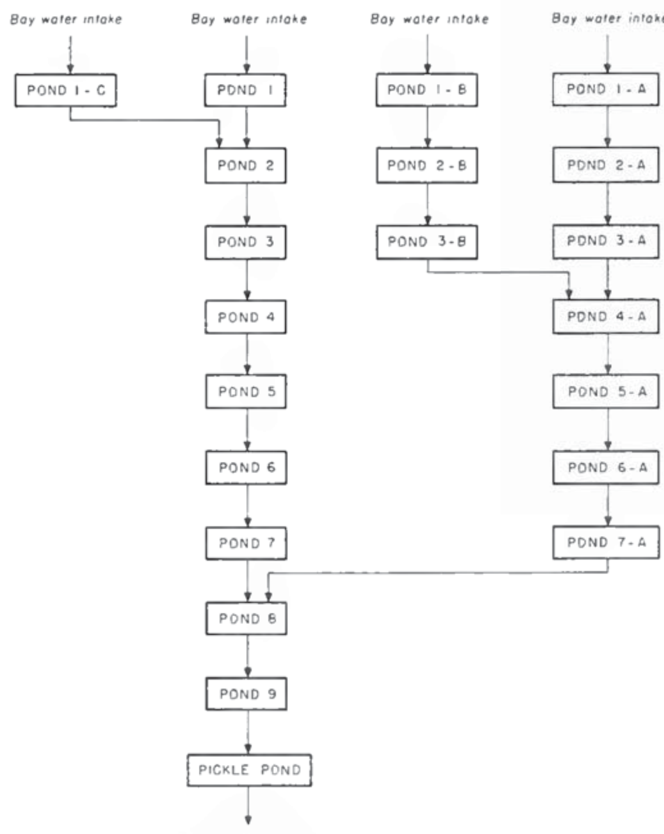

FIGURE 1. Diagram illustrating a complex series of concentrating ponds.

today use mechanized equipment that makes feasible ponds of comparatively large size.

Immediately after harvesting, the salt receives one or more washes with saturated brine followed by a fresh water spray. The salt is stacked in the open without protection.

Most of the salt is marketed as undried crude salt taken directly from the stack without further processing or ground and screened into several sizes. Undried crude salt contains 99.4 percent NaCl. Some salt is rewashed and kiln-dried and some is vacuum refined. The refined vacuum salt contains over 99.9 percent NaCl.

Prerequisites. The commercial production of salt from sea water by solar evaporation depends on three principal factors: the presence of markets, a large area of suitable land, and a dry climate with little rain for at least the greater part of the year. The marketing of salt is discussed in another section of this report.

Suitable land is limited and highly valued. With a maximum yield in the San Francisco Bay area of 40 tons per acre, thousands of acres must be in production. Small salt works of only 100 to 150 acres are in operation today, but to obtain the maximum advantage from mechanized equipment, a single salt works should contain a minimum of 5000 acres. The land ideally should be absolutely level and at or close to sea level. Above all, it should be impervious to prevent leakage of brine. Salt marshes most nearly fulfill these conditions.

For many years salt marshes were considered to be waste land of little value except for salt making, but this is no longer true. Today the salt industry must compete for it with expanding industries and communities. Portions of the marshes must be left open for various public needs such as flood outlets, navigable channels, roads, or utility easements. It is becoming increasingly feasible to reclaim marsh land by draining and filling, and large areas of former marsh land are now covered with houses or industrial plants. The solar salt industry at Long Beach passed out of existence in 1946 when the last available marsh land was filled in and used for other purposes. Elsewhere on the California coast marsh land that could at one time have been used for salt production has been filled in. In San Francisco Bay, marsh land had an assessed value of $150 per acre, a figure reported to be 40 percent of its actual value (Leslie Salt Co., 1953, p. 5).

Net evaporation must be high, and both rainfall and relative humidity must be low during the salt making season. In San Francisco the net evaporation is 34 to 49 inches per year, and an important contributing factor are the strong prevailing northwesterly winds that blow during the summer.

California Plants. The south end of San Francisco Bay most nearly combines all these factors and produces a high proportion of the solar salt manufactured in the United States. The largest producer is the Leslie Salt Co. with plant headquarters in Newark and nearly 30,000 acres of salt land in production in Alameda, Santa Clara, and San Mateo Counties. An additional area is under development on the north shore of San Pablo Bay. This company manufactures practically all grades of salt, including crude, kiln-dried, and vacuum refined. Two other small plants that produce crude salt only belong to the American Salt Company and to Oliver Brothers Salt Company. Both are near Mount Eden. The Morton Salt Company has a plant at Newark in which salt is refined, but that company does not produce crude salt in California.

In addition to the plants on San Francisco Bay, three others on the California coast produce salt from sea water. The Western Salt Company has a medium-sized salt works near Chula Vista on San Diego Bay and a second smaller operation at the head of Newport Bay, Orange County. The third is the Monterey Bay Salt Works at Moss Landing, operated by E. C. Vierra.

In the following pages the production of crude salt from sea water by the California plants is described. Salt refining is discussed in another section of this report.

Operations of the Leslie Salt Co.*

The Leslie Salt Co. (Buchen, 1937; Schrier, 1952) is the largest producer of salt in California and one of the leading producers of salt from sea water by solar evaporation in the entire world. The main office is at 505 Beach Street, San Francisco; and the plant office and principal facilities are on Central Avenue, Newark. Fred B. Bain is President, J. C. Buchen is Vice President and Production Manager, and Sheldon Allen is Secretary and Treasurer. The Company owns 44,000 acres of land on the Bay shore of Alameda, Santa Clara, and San Mateo Counties and additional property on the north shore of San Pablo Bay southwest of Napa. It owns outright the subsidiary Leslie Terminal Company and has a controlling interest in the California Salt Company at Bristol Lake, San Bernardino County.

Facilities included four crude salt producing units in production and a fifth under development at which cars and trucks are bulk-loaded, a deep water terminal for the bulk loading of ships at the Port of Redwood City, an undried crude salt processing plant at Newark, and a refinery at Newark that produces both kiln-dried and vacuum refined salt. The largest crude salt plant, Newark Number 2, lies south and west of Newark around the south end of San Francisco Bay. Another, Newark Number One, is bisected by the eastern approach to Dumbarton Bridge; a third, the Baumberg plant, lies southwest of Mount Eden; and the fourth is on the San Mateo County marshes near Redwood City. A plant under construction near Napa is scheduled for production in 1959.

The Leslie Salt Co. is a consolidation of numerous small plants, some of which had been in production since the 1860's. Corrosion and maintenance of the small plants that were constructed of inferior materials contributed to high operating costs, while lack of capital and volume of business discouraged investment in modern equipment. Most of these small plants adjoined one another so that combining their operations was practical. Consolidation started in 1924. Companies were merged, some plants were dismantled, others were relocated and modernized. The process was completed by 1941.

* Plant visits 1953.
See, D. S., The salt industry, unpublished paper presented at Nonmetallic Minerals Conference, Pacific Chemical Exposition, San Francisco, Oct. 23, 1947.

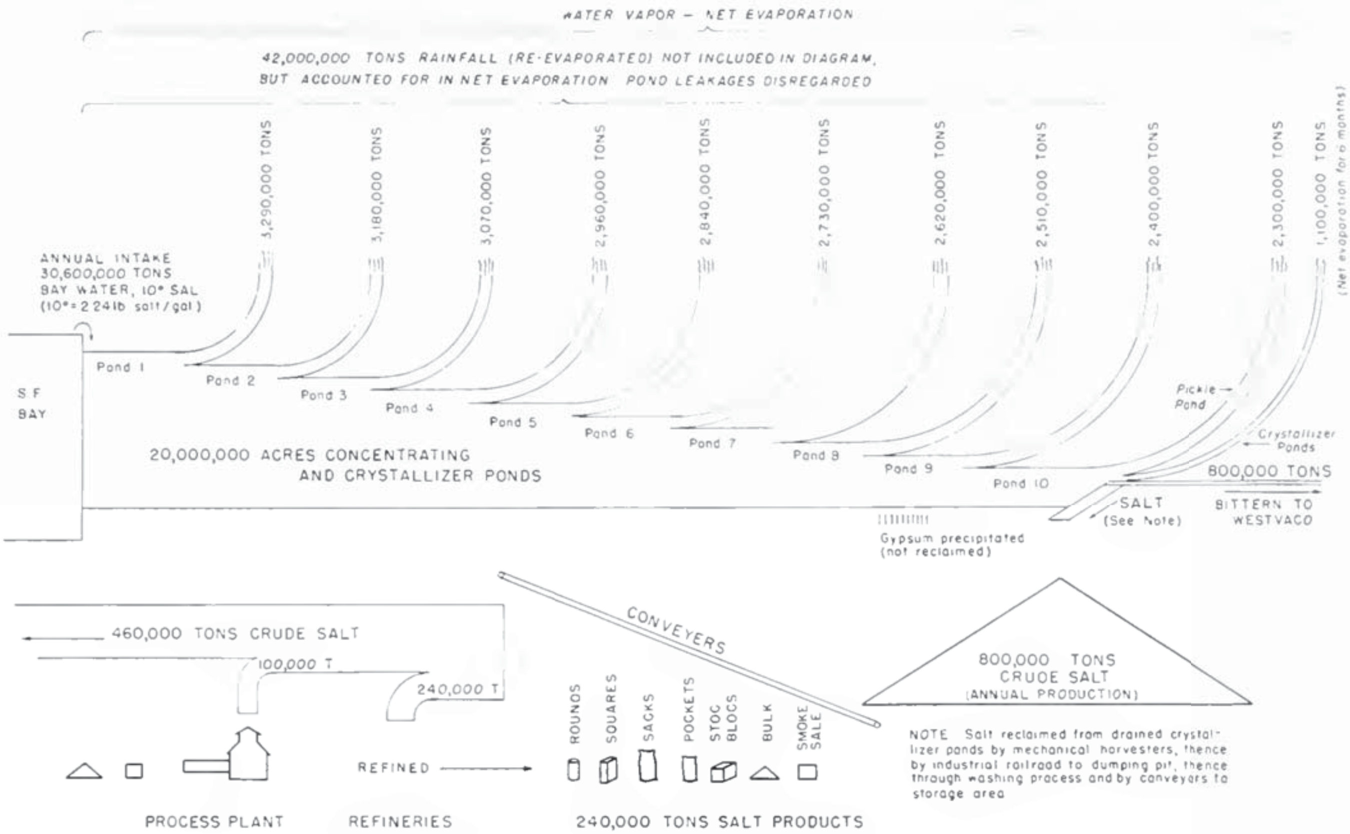

FIGURE 2. Flow chart showing production of salt from sea water.

The growth of the Leslie Salt Co. and its predecessors is startling. In 1936, the year Leslie Salt Co. was incorporated, a production of 300,000 to 325,000 tons was obtained from approximately 12,000 acres of marsh. Ten years later crops of 450,000 to 500,000 tons were harvested, and the area in production had increased to 25,000 acres. In 1952 nearly 29,000 acres yielded 706,000 tons of salt. It is expected that by 1954, 30,000 acres, all that is available in San Francisco Bay, will be in production. By 1959, when the first crop of about 100,000 tons is expected from the plant now under construction near Napa, on San Pablo Bay, production will have reached 1,000,000 tons a year.

FIGURE 3. Crystallizing ponds of the Newark No. 2 crude salt plant, Leslie Salt Co. near Newark, Alameda County. With a maximum yield of 40 tons of salt per acre in the San Francisco area, thousands of acres of marsh land are required. *Photo courtesy Leslie Salt Co.*

Evaporating Conditions. Rainfall in the southern part of San Francisco Bay is 10 to 22 inches per year, and the total evaporation, less rainfall, is 34 to 43 inches per year. The accompanying table shows the monthly mean precipitation and temperature at San Francisco.*

Mean monthly precipitation and temperature, San Francisco.

	Inches of rain	°F
January	4.7	50
February	3.7	53
March	3.1	55
April	1.5	56
May	0.7	57
June	0.2	59
July	0.0	59
August	0.0	59
September	0.3	62
October	1.0	61
November	2.4	57
December	4.4	52

* U. S. Weather Bureau, 1954, Local climatological data, San Francisco.

The net evaporation is concentrated in the seven months from April to October inclusive when low rainfall is combined with low humidity and strong, regular, northwesterly winds. Figures for a typical year are shown in the accompanying table (Phalen, 1917):

Net evaporation, typical year, San Francisco.

	Net evaporation (inches)
April	2.02
May	4.17
June	5.95
July	7.81
August	7.81
September	4.94
October	2.17

Salinity. San Francisco Bay is influenced by the Sacramento River, and its salinity is in general slightly less than that of the open sea. At South San Francisco where the water normally contains 2 grams per liter of magnesium oxide, as little as 0.8 gram per liter may be present when the Sacramento River is in flood. Fortunately for the salt industry, the influx of fresh water is at its lowest during the evaporating season. The accompanying table shows the salinity in degrees salometer (percent of saturation) of water measured at the intake of two of the Leslie plants during 1950 at approximately the first of the month.

*Salinity at Leslie Salt Co. plants, 1950.**

	Baumberg	Newark No. 2
April	9	10½
May	9	10
June	10½	11½
July	11	11
August	10½	12
September	13	12½
October	13	12
November	12	11

* Measured in degrees salometer.

The Marsh Land. The Leslie Salt Co.'s holdings include 40,000 acres of marsh land around the south end of San Francisco Bay. Of this, 10,000 acres cannot be used either because it must be left open for various public needs or because it is in small isolated tracts. The land is typical salt marsh that lies close to sea level and is flooded by spring tides. Meandering sloughs divide the area into tracts of slightly firmer and higher ground where a layer of peat and marsh grass covers soft mud that is impervious to water. The mud varies in thickness from zero at the landward edge to 40 feet at the edge of deep water; and underneath, firmer clays are to be found in most places. (Allin, 1948, p. 82).

The soft bay mud is very unstable and cannot support heavy loads. In former times when the salt plants were built on the marsh, the size of structures, particularly of the stock piles, was strictly limited. The construction of the ship-loading terminal at the Port of Redwood City was an interesting engineering problem that is discussed elsewhere in this report. Except for the Redwood City installations, the present plants are well back from the marsh. At Newark a layer of clay provides support, and piles are necessary for only the heaviest loads.

The Leslie Salt Co.'s property near Napa is former marsh land that was reclaimed for farming many years ago.

The Crude Salt Plants

Each of the four crude salt plants is complete in itself with its own concentrating ponds, crystallizing ponds, harvesting equipment, and washer. Each is normally operated independently of the others, although provision has been made for the transfer of brine between some of the plants to afford greater flexibility of operations. The maximum size of a single plant is limited principally by features such as sloughs and unavailable areas that form natural boundaries. The minimum area for maximum efficiency is a function of the maximum tonnage that one harvesting machine and its auxiliary equipment can efficiently handle during the harvesting season, roughly, 5,000 acres of concentrating and crystallizing ponds. Larger plants ideally would contain multiples of this area. The four plants now in operation depart somewhat from the ideal because of the distribution of the available area, and because their present form was determined in large measure by plants that existed before consolidation began.

Newark Number 2. Newark number 2, the largest of the crude salt plants, lies south and east of Newark. The washing plant adjoins the plant office, refinery, and undried salt processing plant on Central Avenue, Newark, in the northeast quarter of section 12, T. 5 S, R. 2 W., MD. The pond area in 1952 totaled a little over 11,000 acres, and the design capacity is 450,000 tons of crude salt a year. Built about 1929 as the Number 2 plant of the Arden Salt Company, it comprised originally only about 5,000 acres between Newark and Coyote Creek. Since then the plant has been expanded continually. Principal additions have been the ponds of the Alviso Salt Company west of Alviso and ponds constructed between Alviso and Coyote Creek to join the two detached areas.

Baumberg. The Baumberg plant consists of approximately 4,630 acres north of the Coyote Hills between Coyote Hills Slough and the eastern approach to San Mateo Bridge. The washer, which has a design capacity of 180,000 tons a year, is at Baumberg, off Arf Avenue and south of Mount Eden in section 5, T. 4 S., R. 2 W., MD. (projected). The pond area includes most of the important 19th century salt works, and portions have been in production since 1865. The plant achieved its present form when the ponds of the Oliver Salt Company, north of Alameda Creek, were integrated with those of the Leslie-California Salt Company to the south of it.

Newark Number 1. The concentrating ponds of the Newark number one plant are bisected by the eastern approach to Dumbarton Bridge and lie west of the Coyote Hills between Dumbarton Point and Coyote Hills Slough. The washing plant is on Jarvis Road, Newark, in the northeast quarter of section 3, T. 5 S., R. 2 W., MD., and the crystallizing ponds are in the angle formed by Jarvis Road and the Coyote Hills. The design capacity is 160,000 tons a year, and the plant contains approximately 4,400 acres. It was built as plant number one of the Arden Salt Company, which obtained its first crop of salt in 1919. The principal expansion of the pond area has been the inclusion of the northern group of ponds which were operated as a separate unit prior to

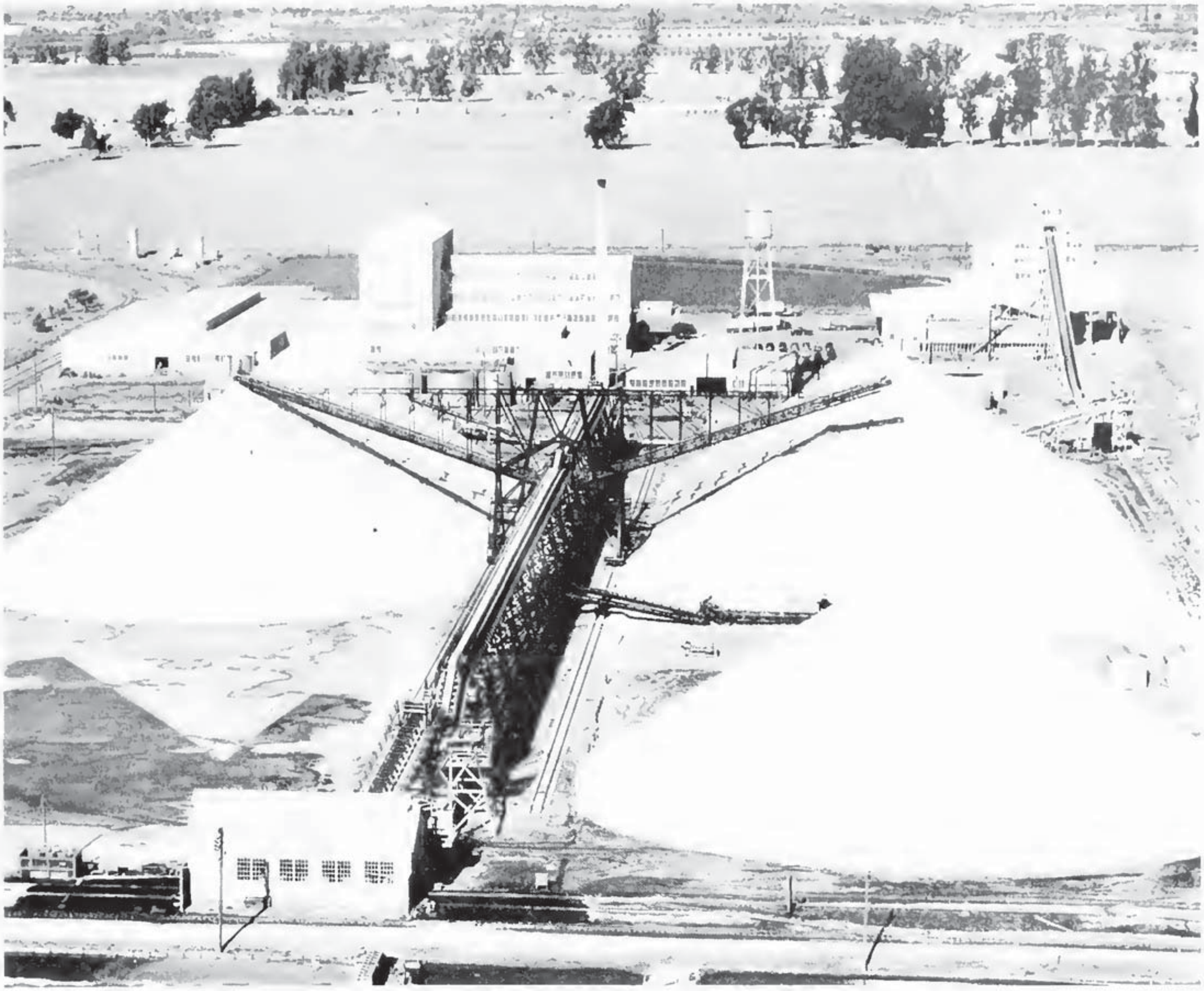

FIGURE 4. Principal plant of the Leslie Salt Co. at Newark, Alameda County. Crude salt stacks, center; washer house, foreground; evaporator house, left center; undried salt processing plant, right.

The Leslie Salt Co., the largest producer of salt in California owns 44,000 acres of land on the Bay shore of Alameda, Santa Clara, and San Mateo Counties and additional property southwest of Napa. Facilities include four crude salt plants plus a fifth under construction, ship-loading terminal, undried salt processing plant, and refinery. *Photo by Elmer Moss, courtesy Leslie Salt Co.*

1940. The present washer is the oldest in operation on San Francisco Bay. It was built in the early 1920's, to replace an earlier plant at Dumbarton Point.

Redwood City. The washer of the Redwood City plant adjoins the ship loading terminal on the west shore of Redwood Creek. The crystallizing ponds are east of the road and railroad running to the Port of Redwood City, and the concentrating ponds extend east and west on the San Mateo County marshes. When full production is reached, 250,000 tons of salt a year will be obtained from an area of approximately 7,200 acres. Salt works formerly operated in San Mateo County were closed in 1941, and the construction of the present plant began about two years later on the same site. Comparatively little of the old engineering works were incorporated into the new plant. Small harvests were obtained in 1951 and 1952, and a capacity crop was expected in 1953.

Napa. During the summer of 1953 construction began on a new plant near Napa that is expected to be in production by 1959. The property lies between Napa River and Napa Slough and extends from Buchli siding southward toward San Pablo Bay.

Concentrating Pond Systems

The evaporating ponds of the four plants now in opertion are shown on the accompanying map. Concentrating ponds, in which the water is brought to saturation, are of irregular shape and from 100 acres to 500 acres or in a few cases even larger in size. Their depth is shal-

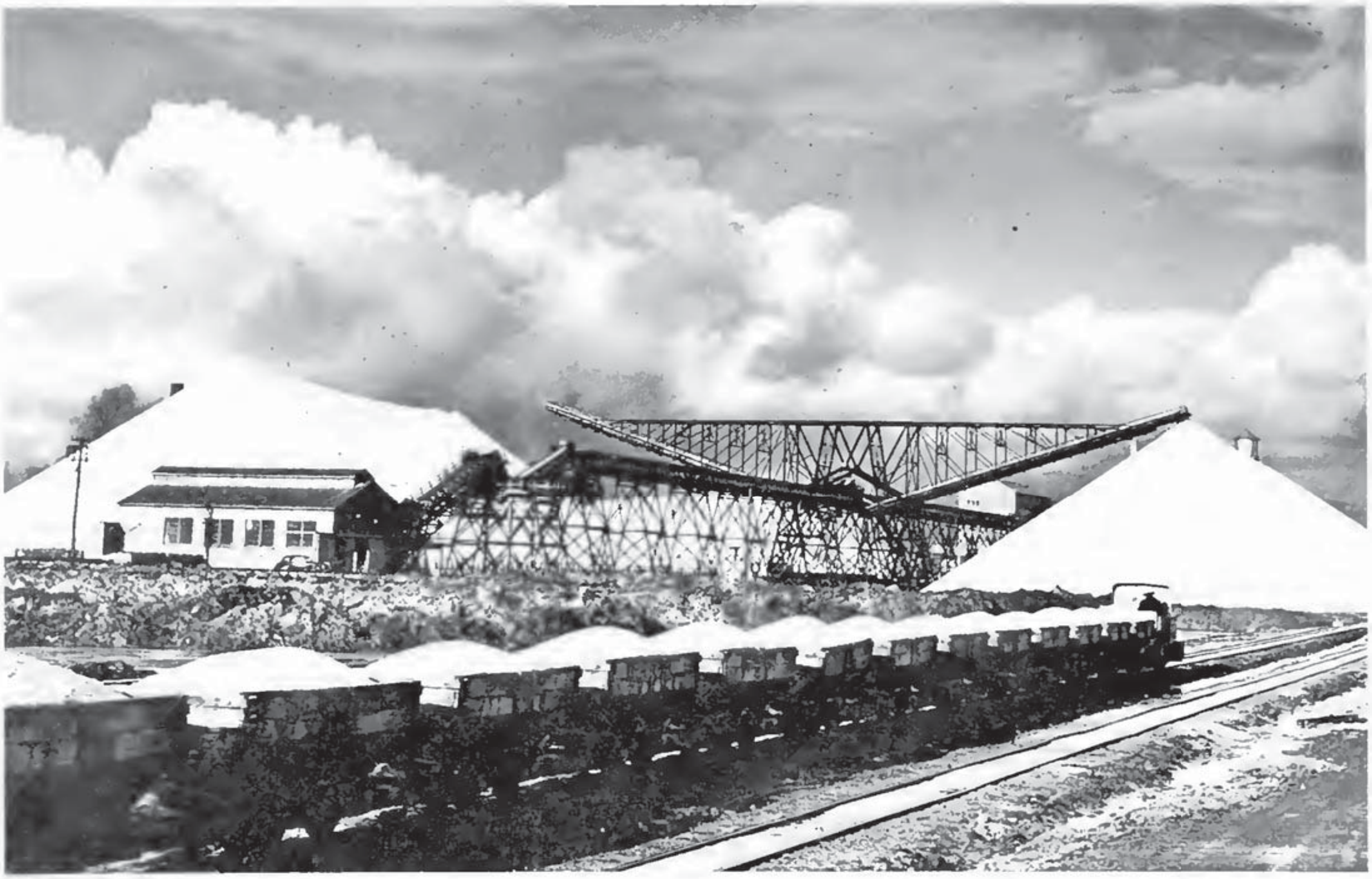

FIGURE 5. Newark No. 2 crude salt plant, Leslie Salt Co. Photo shows loaded train approaching washer house (left center), gantry stacker, and crude salt stacks. With a pond area of a little over 11,000 acres, the design capacity of the Newark No. 2 plant is 450,000 tons of crude salt per year. *Photo by Don Krogh, courtesy Leslie Salt Co.*

low to allow maximum exposure of the brine to tne sun and wind. Levees are not built across sloughs if it can be avoided, and consequently the ponds occupy the areas between sloughs. Pond systems are designed so that the flow of brine from pond to pond is by gravity through control gates. Pumping cannot be entirely eliminated, and often a pump is combined with a syphon to transfer brine across a slough. Wherever possible brine is partially concentrated and its volume reduced before handling it with pumps. Gates are constructed either of iron or of creosoted wood. While the treated wood lasts longer than iron, the action of teredos makes it difficult to keep wooden gates tight. The wooden gates are being replaced with iron ones.

It will be noted that the concentrating ponds of none of the plants are arranged in the theoretical simple series of ten. Each plant has in effect several parallel series in which water taken in at a number of points is partially concentrated before joining the common path to the pickle pond. Such a system is schematically shown on the accompanying diagram. Some of these branches are ponds of formerly independent plants that have been tied into the larger system; others are new ponds that have been added to an existing plant.

The Construction of Levees. The Leslie Salt Co. is constructing new levees for its expanding operations almost continuously, and a technique has been developed, using clamshell dredges that float in their own borrow pits. Care must be taken not to break through the thin, weak surface crust of the marsh by building the levee too rapidly. If the crust is broken, it is very difficult to build the levee up to the required elevation. Erosion and slow settlement require periodic maintenance.

Outside levees are 40 feet wide at the base, 12 feet wide at the top, and $3\frac{1}{2}$ feet high. To prevent leakage between the base of the levee and the old surface, the levee is keyed to solid material by coring. In coring, a trench is dug through the grass and peat along the center line of the levee and filled with clean mud. Cross levees, or levees that separate one pond from another, may be slightly lower and usually are not cored.

Levees are constructed in stages. The borrow pit of a finished levee averages 50 to 55 feet wide and 5 to 6 feet deep, or 10 cubic yards per linear foot. This compares with the design section of 3.37 cubic yards per foot of the finished levee and reveals the extent of shrinkage and settling that takes place.

On the first pass the dredge places 60 percent of the material that will be required, and the levee is built to a maximum height of three feet. The borrow pit is dug 38 feet wide by $4\frac{1}{2}$ feet deep, just large enough to accommodate the dredge which draws four feet when listing.

FIGURE 6. Baumberg crude salt plant, Leslie Salt Co., south of Mount Eden. The pond area of the Baumberg plant, which includes most of the important 19th-century salt works, is 4,630 acres. The washer (center) has a design capacity of 180,000 tons a year. Bulk shipments only are made from the bunker (right). *Photo by Elmer Moss, courtesy Leslie Salt Co.*

An extra 6 inches is allowed because the water level averages that distance below the surface of the marsh. After drying for 6 to 18 months the levee will have settled to a height of only 2 feet in places.

On the second pass 20 percent of the material is placed, raising the levee initially 1½ to 2 feet. After consolidation the final height may be 3 feet. The borrow pit is widened in the direction away from the levee.

The final 20 percent of the material is placed on the third pass, raising the levee initially to 4½ feet. After drying the height has shrunk to 3½ feet. The borrow pit is deepened on the side away from the levee. Thus the possibility of the levee's failing is reduced, and clean mud free from vegetation or peat is available for topping.

If a slough must be crossed, it may be necessary to drive sheet piling to retain the levee. Sections that are exposed to erosion are reinforced.

In the operation of the dredge, one swing of the bucket across the borrow pit is called a "fleet." Nine to twelve 2-cubic-yard buckets full comprise a fleet, which equals a 4-foot advance. Usually the dredge is set ahead after completing each fleet, but two or three fleets can be dredged from one position. Fifteen minutes are required to complete a fleet. Time is lost in coring, setting ahead, damming small sloughs, and in moving to new locations, so that the average rate of advance is 10 feet per hour on the first pass.

Even after the levees are completed and a pond is flooded, production cannot begin at once. Impervious though the bay mud is, seepage takes place until the bottoms have been sealed by the slow precipitation of calcium carbonate and gypsum. This sealing process is complete only after 5 to 7 years.

The Concentration Process. Bay water is taken in through automatic gates that open at high tide and close when the tide drops below the pond level. Where possible the gates are placed in north or northwesterly facing levees to take advantage of the prevailing wind. The intake at some points is by means of pumps.

During the evaporating season brine is passed slowly through the system of concentrating ponds as evaporation in the pond ahead requires replacement. The flow is controlled by gates and pumps that are reached by roads built on the levees. Every pond is examined once a week, and both the salinity and the depth of the brine are recorded.

It has been pointed out that as the result of growth and physical limitations, the concentrating ponds are arranged in rather complex, branching systems. The progress of the brine concentration may be illustrated, however, by the simple series of eight ponds followed by a pickle pond shown in the accompanying diagram. In the first stage, ponds one through six, evaporation has raised the concentration of the brine to a specific gravity of 12.9° Be and reduced the volume to nearly half of that taken in. Suspended matter settles, carbonates precipitate, and the precipitation of gypsum begins. In the second stage, ponds seven through nine, evaporation continues until, at 25.6° Be, the brine is saturated with respect to salt. By the time the specific gravity has reached 25.0° Be, most of the gypsum has precipitated. Some salt precipitates also at 25.0° Be, but any that forms in the pickle pond is dissolved when the concentration is reduced by the next filling with weaker brine. By the time the brine is ready to leave the pickle pond, its volume has been reduced by evaporation to about ten percent of the volume of bay water taken in.

The accompanying sketch portrays the vast quantity of water that must be evaporated. In order to produce 800,000 tons of salt, 30,600,000 tons of bay water containing 0.22 pounds of salt per gallon (10° salometer)

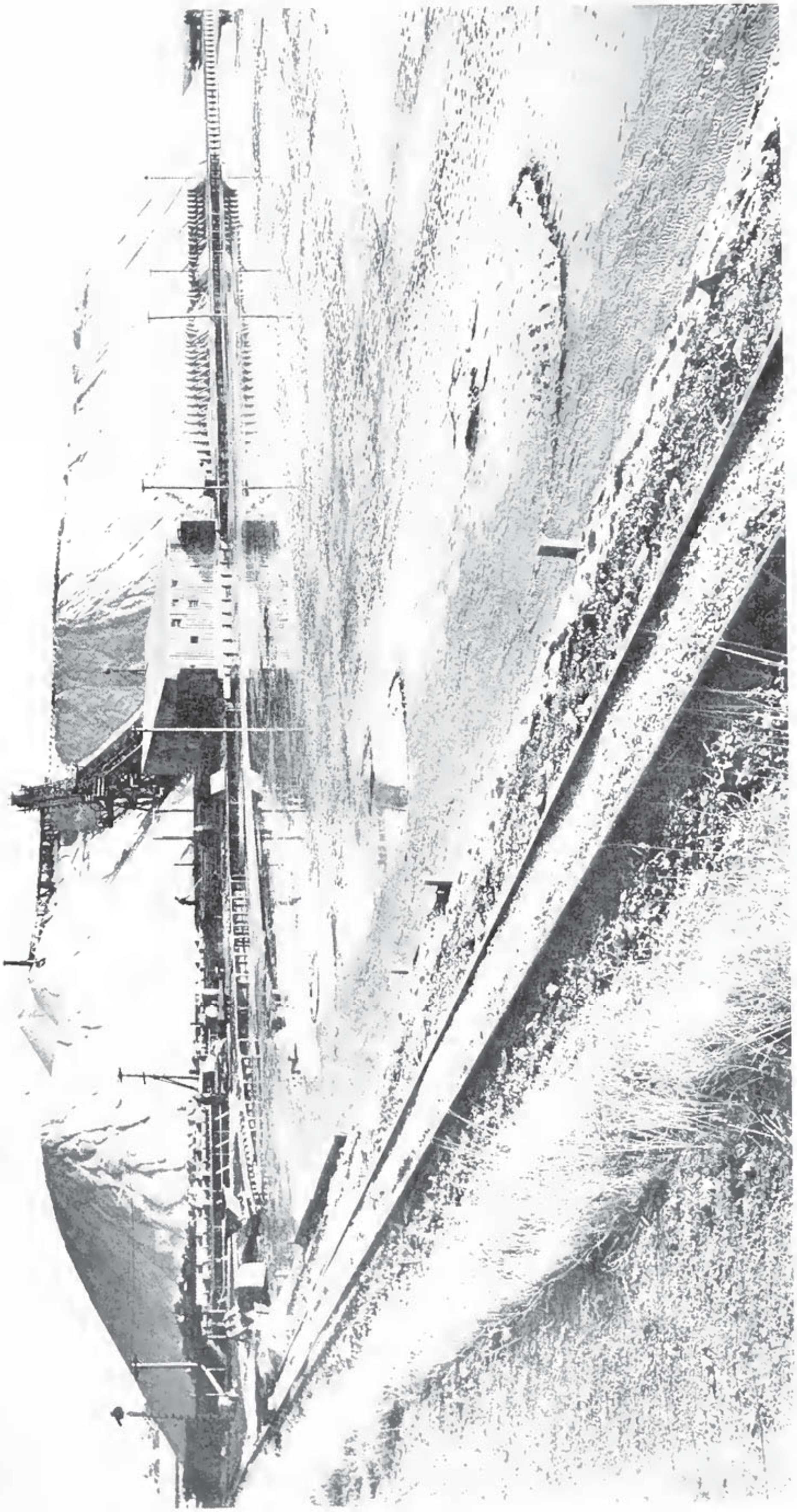

FIGURE 7. Newark No. 1 crude salt plant, Leslie Salt Co., Jarvis Road, Newark. The Newark No. 1 plant was built as plant No. 1 of the Arden Salt Company which obtained its first crop of salt in 1919. The present washer, which has a design capacity of 160,000 tons a year, was built in the early 1920's to replace an earlier plant at Dumbarton Point. *Photo by Gabriel Moulin Studios, courtesy Leslie Salt Co.*

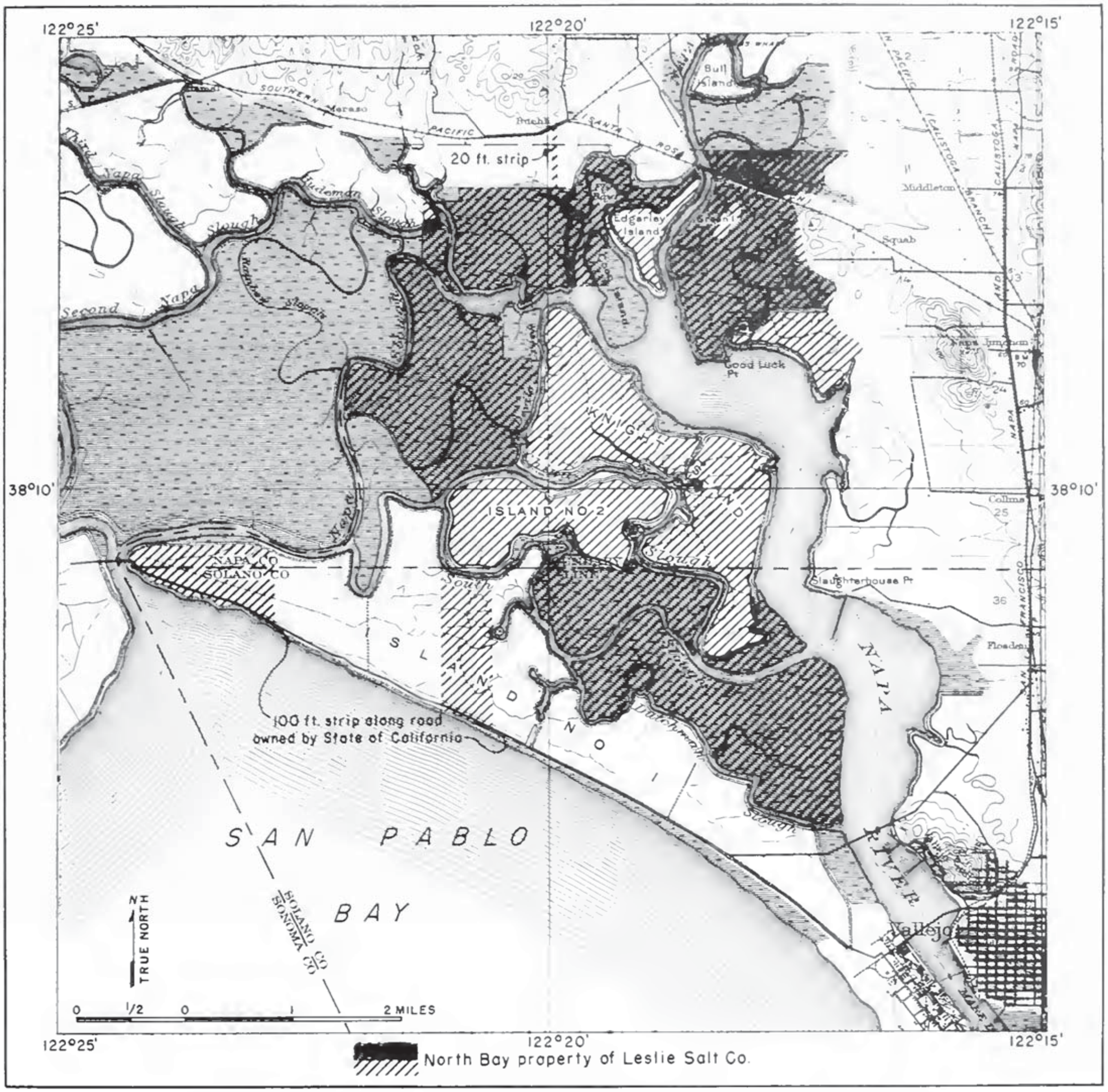

FIGURE 8. Map showing location of Leslie Salt Co.'s North Bay property as of July 1953.

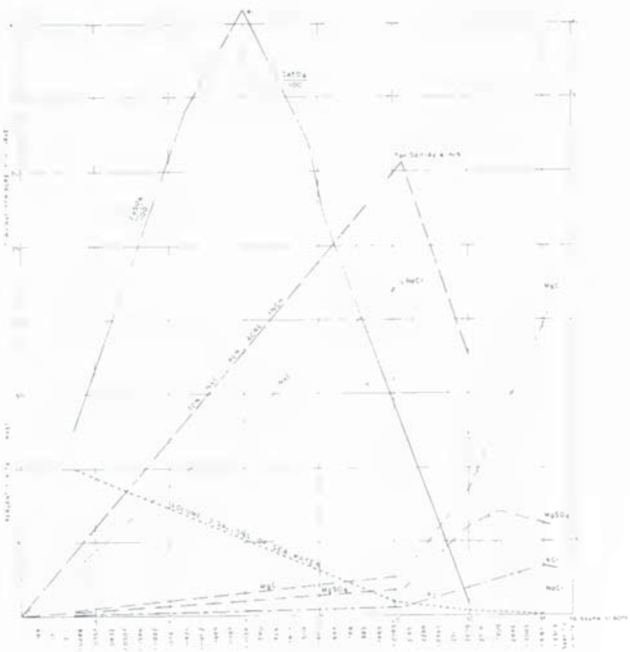

FIGURE 9A. Graph showing the composition of normal brine at various concentrations.

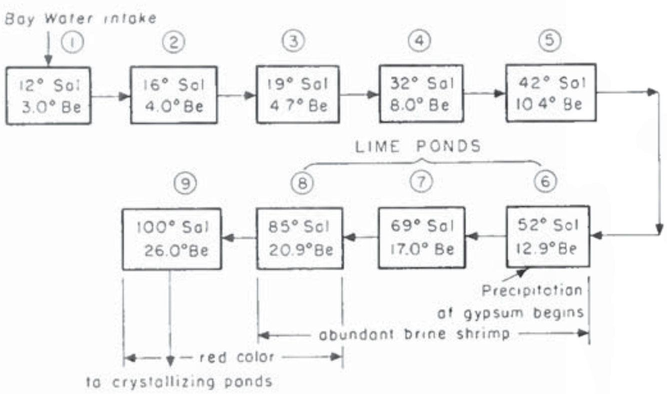

FIGURE 9B. Diagram illustrating the progress of brine concentration in a series of concentrating ponds.

are required. The amount of water evaporated is 29,000,000 tons, yielding 800,000 tons of salt and 800,000 tons of bittern.

Interesting biological changes take place in the evaporating ponds (Peirce, 1914). Pond one contains live fish and the numerous micro-organisms present in sea water, and the water is muddy. In ponds two, three, and four (4°-8°Be) the sea water forms are dying, and new forms of life are appearing. In pond five (10° Be) no fish remain alive. Gray colored brine shrimp (*Artemia salina*) and yellow algae (*Dunaliella viridi*) appear and thrive on dead matter. The algae color the water yellowish. Shrimp and algae continue to thrive in ponds six and seven (13°-17° Be), and the shrimp aid in the precipitation of calcium carbonate and calcium sulfate. Additional micro-organisms appear in pond eight (20° Be) including red chromogenic bacteria that color the water red. Shrimp feed on the red bacteria and turn from gray to red. Algae and shrimp are dying in pond nine (26° Be). The red bacteria remain healthy until the brine has become a bittern of specific gravity 34° Be. As they die and settle to the bottom the bittern turns from red to light brown in color.

Bay water is taken in during the highest tides and when the salinity of the water is highest. Depending on the year, the intake period begins in April or May and lasts through October or November. During the winter little if any evaporation occurs, and the concentrating ponds lie idle. Rain water lies on the surface of strong brine and does not mix with it appreciably unless the wind is strong. A year is believed to be required for raw bay water to pass through the concentrating ponds and reach the pickle pond. Pickle is available for flooding the crystallizing ponds as soon as the winter rains are over, usually in April.

The Crystallizing Ponds

The ratio of concentrating to crystallizing pond area is about 15 to one, considerably more than the theoretical ratio of ten to one. The extra area of concentration pond is required because of pond leakage and dilution by rain water. Crystallizing ponds are rectangular in shape and have flat, grass-free bottoms with a slope of 1 inch per 300 feet to one corner to facilitate emptying. Individual ponds range from 20 acres or less to more than 60 acres in size. The size is determined by the capacity of the harvesting machine. With smaller ponds more time is lost in transferring equipment from one pond to

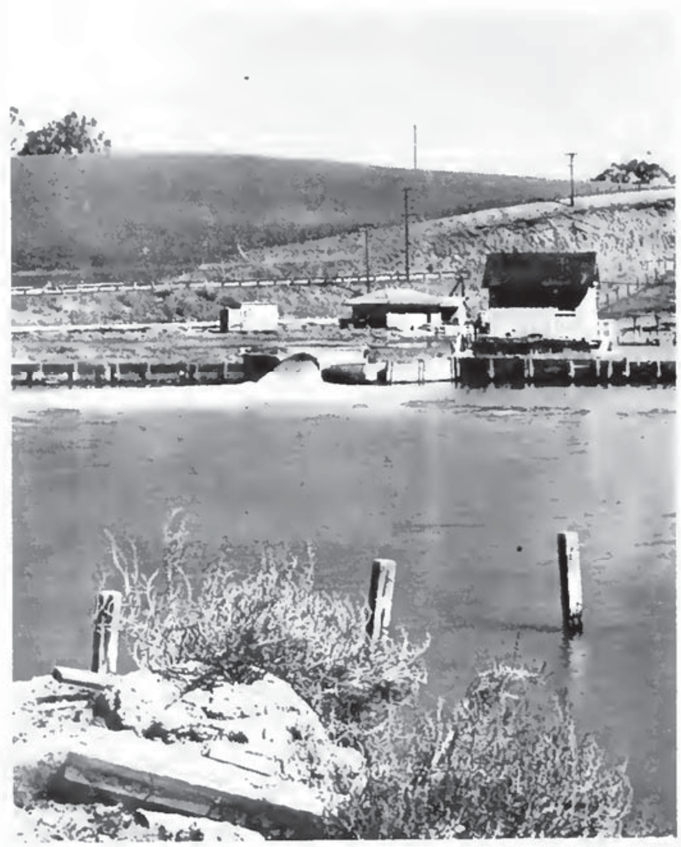

FIGURE 10. Pumping brine. Intake pump of Newark No. 1 crude salt plant, Leslie Salt Co. Wherever possible brine is partially concentrated and its volume reduced before handling it with pumps. *Photo courtesy Leslie Salt Co.*

FIGURE 11. Brine ditch with control gate, Leslie Salt Co. The flow of brine between ponds is controlled by gates that are reached by roads built on the levees. *Photo courtesy Leslie Salt Co.*

another, while with larger ponds salt is left exposed for a longer time.

Crystallizing ponds are provided with an elaborate system of ditches and pumps for rapid filling and emptying. Two 40-horsepower pumps of 5,000 gallons per minute capacity serve the crystallizing ponds of the Newark number 2 plant; and for maximum flexibility and control, pickle may be drawn from any of the last three concentrating ponds.

Pickle flows from the supply ditch to the concentrating ponds, and from thence bittern ditches carry bittern away. Close control is required to prevent, as far as possible, the precipitation of either gypsum or bittern salts in the crystallizing ponds. Pickle enters at 25.6° Be, and bittern is withdrawn at 29° Be. An effort is made to keep the specific gravity within these limits by continuously drawing off a small amount of bittern. Two to five times during the season, however, it is necessary to empty the ponds and refill them with fresh pickle.

As evaporation continues, tiny seed crystals of salt form on the surface and are supported by surface tension. As their weight increases, they sink deeper. Growth is fastest on the upper edges, and distorted, hopper-shaped crystals form. Crystals sink when they are heavy enough to overcome surface tension. Large intergrown crystals form on the bottom, often with faces two inches or more long. During the season 4 to 6 inches of salt forms, and about 70 percent of the salt in the pickle is extracted.

Bittern is brought from the crystallizing ponds to bittern ponds where further evaporation raises the specific gravity to 30° Be, and some additional salt forms. The Westvaco Chemical Division of Food Machinery and Chemical Corporation currently purchases all of the bittern that the Leslie Salt Co. produces. The facilities for transferring the bittern from the various bittern ponds to storage reservoirs are owned and operated by the chemical company.

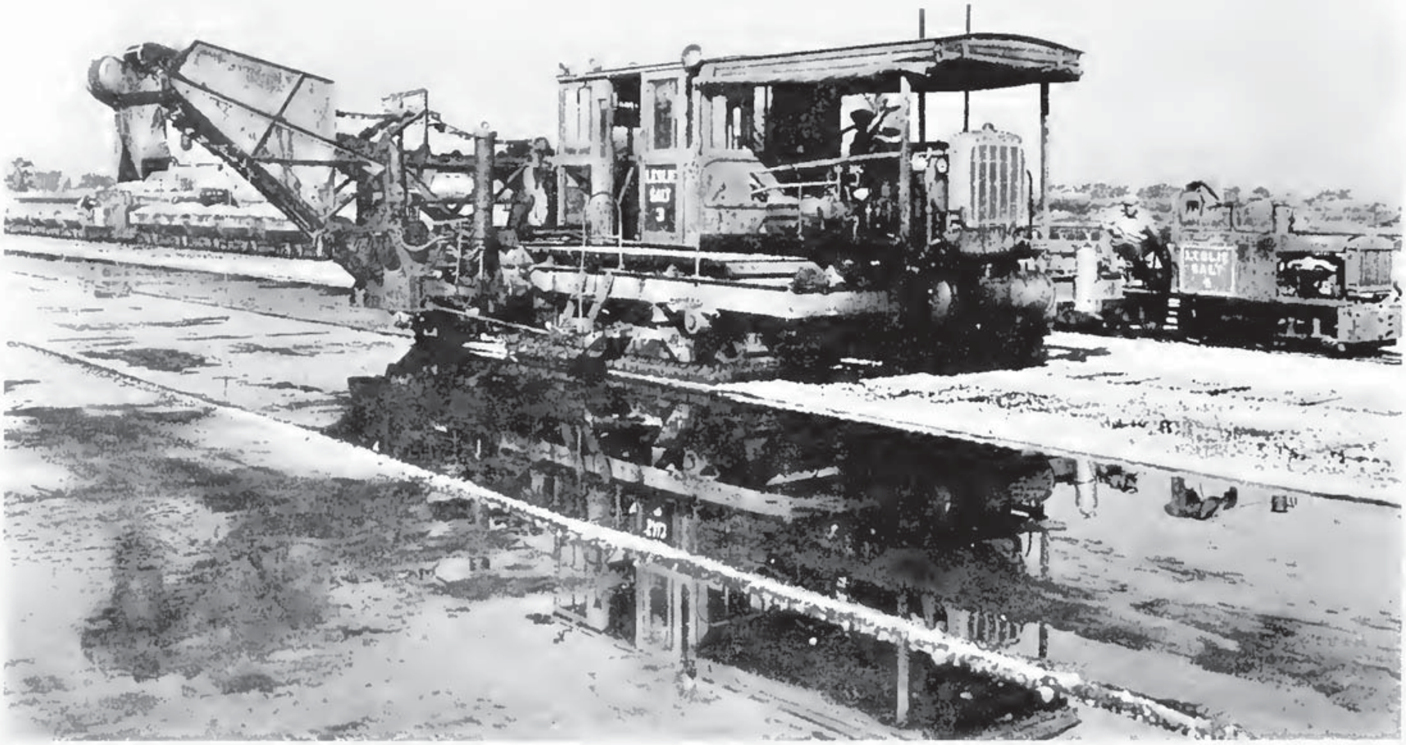

FIGURE 12. Harvesting machine, Leslie Salt Co. A view from the side. The cutter, which is mounted on the rear of a caterpillar type tractor, is essentially a horizontal, revolving shaft bearing picks. Salt is broken free by the picks and thrown onto a short drag conveyor that carries it to the waiting cars. When the salt is four inches thick, loading is at the rate of 150 tons per hour. *Photo by Gabriel Moulin Studios, courtesy Leslie Salt Co.*

*A typical analysis of bittern at 30° Be.**

	Percent
$NaCl$	12.5
$MgCl_2$	8.7
$MgSO_4$	6.1
KCl	1.9
$MgBr_2$	0.18

* After Seaton, 1931.

After the bittern ponds have been emptied the salt that forms in them is dissolved with weak brine and returned to the concentrating ponds. This salt is of the same high quality as that which forms in the crystallizing ponds. Above 29° Be, however, the rate of crystallization is so slow that it does not pay to keep the bittern in the crystallizing ponds any longer.

The Harvest

Mechanization makes it possible to continue the crystallizing season into the fall yet to complete the harvest before the winter rains begin. Harvesting starts around October first and continues 24 hours a day, seven days a week until it is finished, usually toward the end of December. One pond at a time is drained and harvested. Salt is left uncovered in the ponds for as short a time as possible. Not only does salt harden upon exposure to the air, but the thin layer of salt spread over the broad pond is particularly exposed to showers when it is not covered with pickle. In addition, no salt forms after the pond has been drained.

The Harvesting Machine. The harvesting machine is a unique piece of equipment that was perfected in the 1930's. The cutter, which is mounted on the rear of a caterpillar-type tractor, is essentially a horizontal, revolving shaft bearing picks. Salt is broken free by the picks and thrown onto a short transverse drag conveyor. The conveyor is carried by means of wings to loading chutes, one on each side; and the conveyor is reversible so that loading is done on either one side or the other. The tractor, which is supported on wooden tracks about

FIGURE 13. Harvesting machine, Leslie Salt Co. A close view from the front. *Photo by Elmer Moss, courtesy Leslie Salt Co.*

five feet wide, runs on the salt and drags the cutter behind it. The elevation of the cutter, the conveyor wings, and the loading chutes are adjusted hydraulically. The harvesting machine cuts a swath 13 feet 8 inches wide and 4 to 6 inches deep. The speed may be varied from 5.34 feet per minute to 16.7 feet per minute. When the salt is four inches thick, loading is at the rate of 150 tons per hour.

Six machines are in operation, one older machine is held in reserve as a spare, and an additional machine is under construction. Three are powered with D-7 diesel tractors, three with D-6 tractors, and the older machine has a gasoline engine. Two are used at the Newark number 2 plant, two at the Redwood City plant, and one each at the Newark number one and Baumberg plants.

Transporting the Salt. Salt is transported from the ponds in narrow-gage cars. Trucks would be difficult to use because the salt has limited bearing capacity and because of the possibility of tracking stones from the gravel roads onto the salt. The railroad systems that serve the four salt producing units total approximately 75 miles of track and have 26 locomotives. Four-ton Vulcan gasoline-powered locomotives comprise the greater part of this number, but there are a few five-ton gas-electric locomotives and some other experimental models. Four Caterpillar straight diesel locomotives are under construction. The track gage is 24 inches at the two Newark plants and 30 inches at the Baumberg and Redwood City plants. Except at Newark Number one, where side dump cars are used, the cars have wooden bodies and bottom dumps. They have a capacity of about two tons of moist salt and weigh 1500 pounds. Permanent tracks are laid on the levees and temporary tracks on the salt in the form of a loop so that the trains always run in the same direction.

The Harvester in Operation. In the harvesting operation the basic unit consists of the harvesting machine,

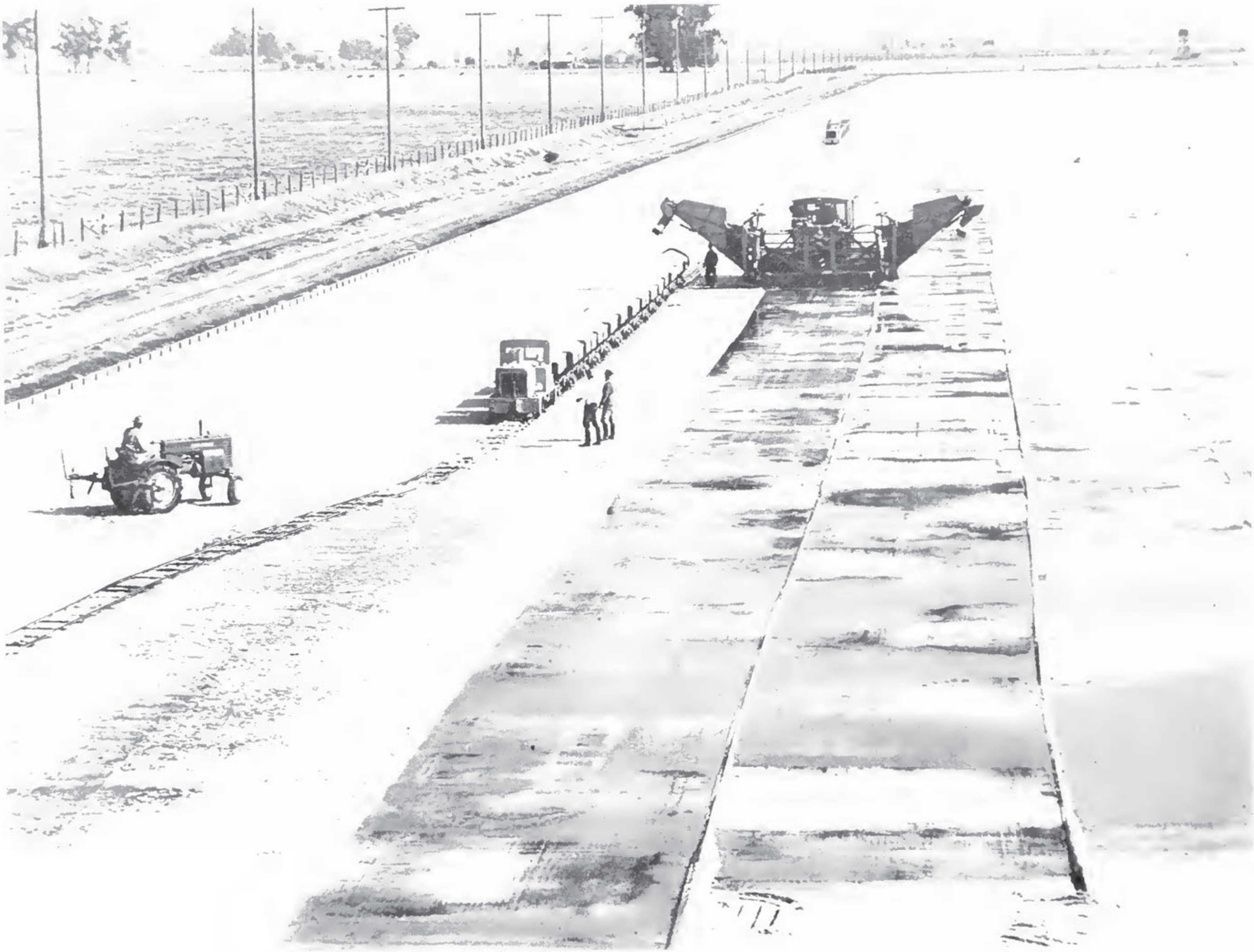

FIGURE 14. The havesting machine in operation, Leslie Salt Co. Each harvesting machine is served by four trains of 12 to 14 cars. Permanent tracks are laid on levees and temporary tracks on the salt. *Photo by Elmer Moss, courtesy Leslie Salt Co.*

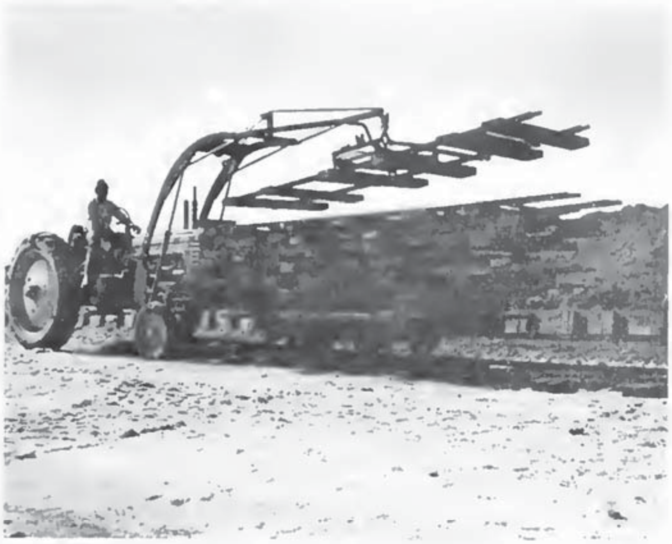

FIGURE 15. Equipment for laying portable track in the pond, Leslie Salt Co. *Photo by Elmer Moss, courtesy Leslie Salt Co.*

washer, four trains of 12 to 14 cars each, and track shifting equipment. At Newark number 2, where there are two machines, each operates entirely independently of the other and has its own dumping pit. Nine men are required: two men on the harvesting machine, four locomotive operators, one man plus one helper to operate the track shifting equipment, and one at the dumping pit.

The loading machine cuts a swath parallel to the long side of the pond. Trains run on portable track laid on the salt parallel to the swath and are loaded as they slowly pass the moving machine. Thirteen cars are heap loaded in 8 minutes. At the end of the swath the machine is turned around and cuts another swath parallel to the one just completed. In this way the harvest progresses across the pond.

After the harvest the crystallizing ponds are flooded with weak brine to dissolve any salt that remains, particularly fine salt that accumulates on the windward sides. The brine is returned to intermediate concentrating ponds, and the crystallizing ponds are prepared for the next season. They are allowed to dry almost to the point where dust would blow from them, then leveled with scrapers and rolled.

Portable Track. The portable track is built of panels about 15 feet long composed of light rails permanently fastened to light steel or wooden ties. In laying the portable track, panels are brought to the pond on flat cars, and the track is extended onto the salt from spurs of the permanent tracks on the levees. A rubber-tired tractor with a special boom places the panels in position. After a panel has been loosely joined with splice bars to the track already laid, the tractor pulls the flat car ahead and places the next panel.

Track is shifted without uncoupling it after the harvesting machine has passed. A rubber-tired tractor equipped with a special tool bar moves it to the new position, one section at a time, without interrupting traffic. One tractor operator and a helper are required.

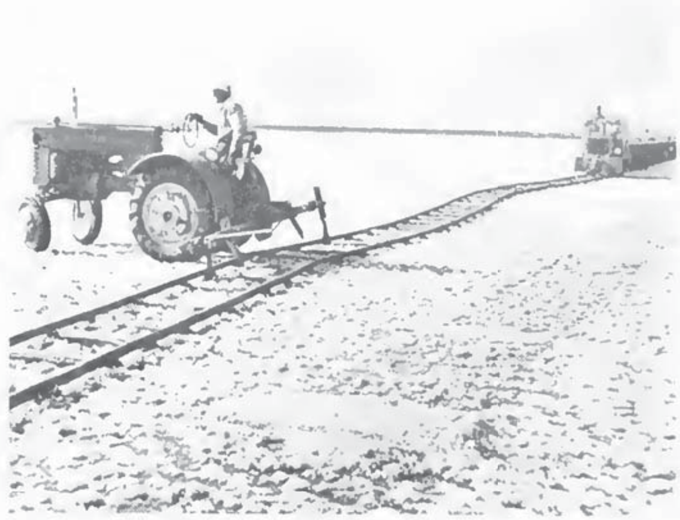

FIGURE 16. Track shifting, Leslie Salt Co. After the harvesting machine has passed, the track is shifted with a tractor equipped with a special tool bar. Traffic is not interrupted. *Photo by Herrington-Olson, courtesy Leslie Salt Co.*

Special materials are not required for equipment used about the ponds. For most purposes ordinary iron is practical if corrosion is combatted with a rigorous program of scraping and painting. Some pump sumps and flumes are constructed of wood.

Washing

Salt is washed immediately after harvesting and then placed in outside storage piles. The salt from the ponds contains on the average 97.8 percent NaCl. Impurities are mud scraped up from the pond bottoms, gypsum, which cannot be entirely prevented from precipitating in the crystallizing ponds, and adhering bittern. Washed salt in the stacks contains 99.4 percent NaCl.

The washers at all four plants are essentially the same but have had additional equipment added to increase their efficiency. The basic operation is a wash with concentrated brine in a mechanical classifier that separates the salt from the dirt. This may be followed by additional brine washes and a fresh water spray to remove the adhering magnesium-bearing brine.

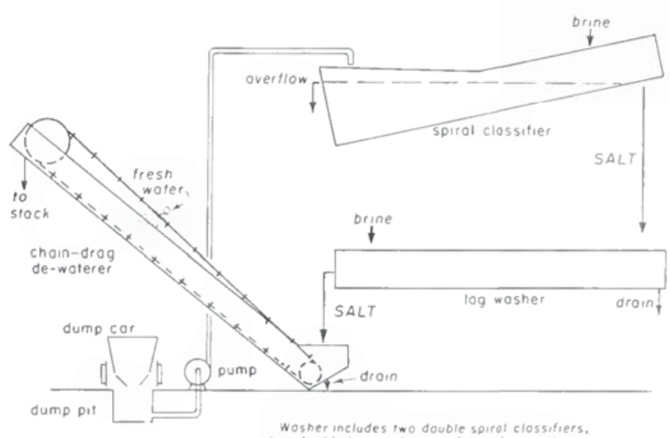

FIGURE 17. Typical washing plant, Leslie Salt Co.

FIGURE 18. Dumping salt at the washer, Leslie Salt. Co. The cars are discharged into rectangular brine-filled pits beneath the track. *Photo by Gabriel Moulin Studios, courtesy Leslie Salt Co.*

At the Newark number 2 unit, the washer is built in two nearly identical sections, one for each harvesting machine. Cars dump into rectangular pits inside the washer house and beneath the track. The dumping pits contain concentrated brine, and centrifugal pumps transfer the salt in slurry form to two washing tanks, each of 150 tons per hour capacity. At the Redwood City plant, the dumping pit and washer are separated by about half a mile of pipe line.

Each washing tank contains a double 2- by 20-foot spiral classifier that provides violent counter-current agitation. Dirty wash brine overflows from one end, while dewatered salt is raised from the other. The washing tanks are followed by vibrating screens that reject plus 1 inch material, mostly clay balls; and the undersize goes to double steel 2- by 20-foot log washers where the remaining lumps of clay are broken up. The streams from the two sections of the washer unite in an inclined 10 by 100-foot dewatering drag, the lower section of which is perforated to allow the salt to drain. After a final spray of fresh water, the salt is sent to storage. Dirty wash brine from all parts of the washer is collected and returned to the wash brine circulating pond where dirt and gypsum settle. Some wash brine is continuously bled off and replaced with fresh pickle to prevent the build-up of magnesium salts. The wash pond must be cleaned of accumulated sediments every few years.

Salt Storage

The gantry stackers that are familiar landmarks at Newark and Baumberg were designed by engineers of the Arden Salt Company, one of the Leslie Salt Co.'s predecessors. A trestle 50 feet high and 600 feet long carries a conveyor belt that receives salt from the washer. The gantry tower straddles the trestle on legs

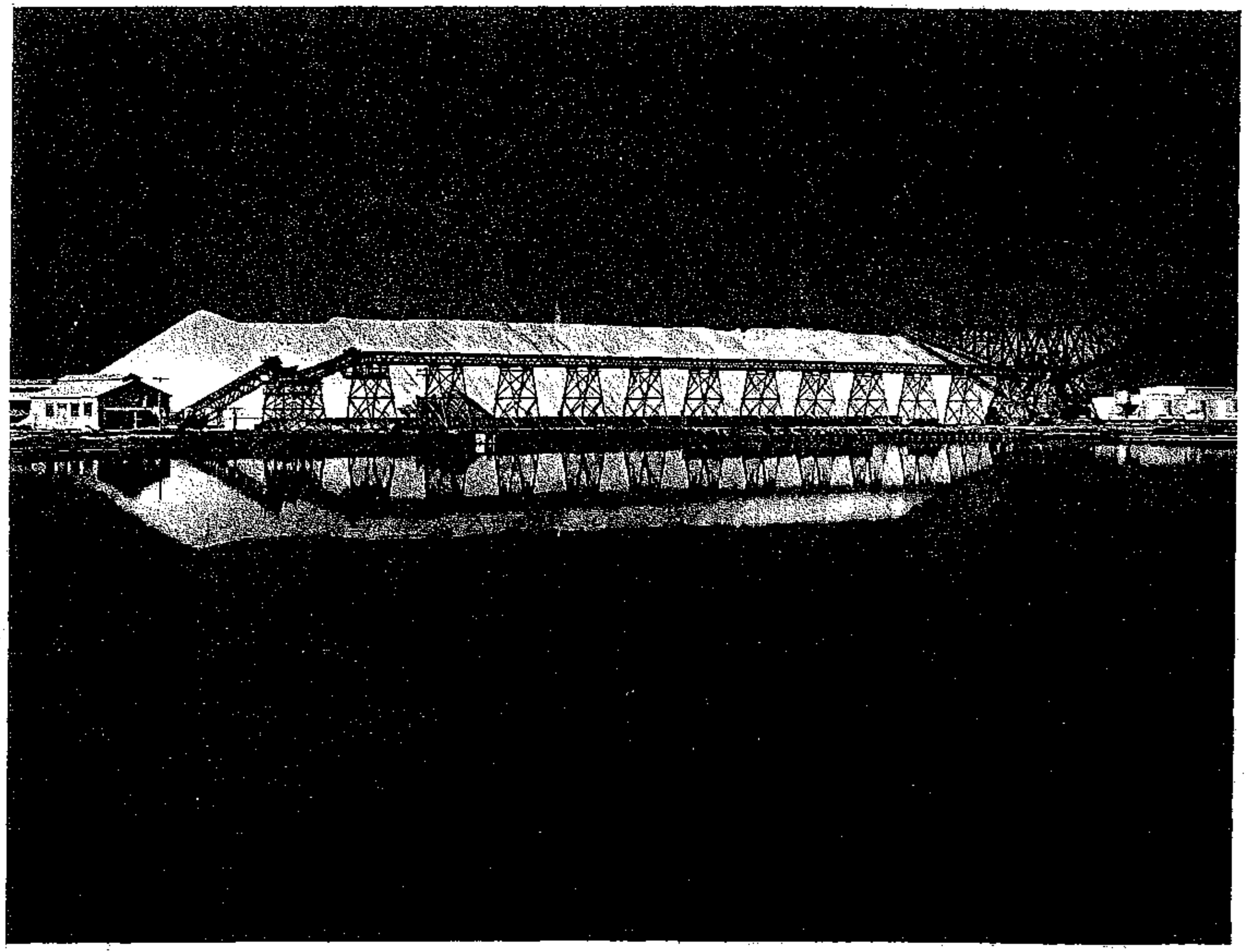

FIGURE 19. Gantry stacker and stock pile of crude salt, Newark No. 2 crude salt plant, Leslie Salt Co. A trestle 50 feet high and 600 feet long carries a conveyor belt that receives salt from the washer (left). The gantry arms are 100 feet long. Two stock piles are formed holding as much as 300,000 tons of salt each. *Photo by Gabriel Moulin Studios, courtesy Leslie Salt Co.*

that are mounted on tracks, one track on each side of the trestle and parallel to it. Stacking arms 100 feet long and projecting at right angles in both directions carry conveyor belts that are fed from the trestle belt. Two stock piles are formed, each containing as much as 300,000 tons.

At the Newark number one plant, stacking is done with an inclined belt-conveyor that has been extended a number of times to provide increased storage capacity. Storage facilities at the Redwood City plant are part of the shiploading terminal and are described in another section of this report.

Almost always enough salt remains from the previous season so that the newly havested salt can drain for a month or two in the stacks. This practice yields a drier product and increases the purity somewhat. When the salt is exposed to the weather a hard surface crust forms that tends to shed rain water. Loss from rain is about five percent a year.

Processing Crude Salt for Market

The greater part of the Leslie Salt Co.'s production is shipped in bulk as stack run, undried, crude salt taken directly from the stock piles without further treatment. Rail and truck shipments are made from the plants in Alameda County, while the bulk loading of ships is carried out at the Port of Redwood City facilities. A portion of the stack run salt is shipped in paper or textile bags, and some is processed into three screen sizes before being shipped in bulk or in bags.

The Undried Salt Processing Plant. The undried salt processing plant is at Newark and is supplied exclusively from the nearby stock piles of the Newark number two crude salt plant. Bulldozers on the stacks push the salt to portable loading boxes that feed portable drag chain conveyors. These in turn feed a permanent belt conveyor between the two stacks and at the base of the stacking trestle. A transfer belt carries the salt to a final belt that leads to the top of the undried salt proc-

FIGURE 20. Reclaiming salt from the stock pile, Leslie Salt Co. Bulldozers on the stack push the salt to portable loading boxes at the base from which it is transferred to conveyor belts. *Photo by Caterpillar Tractor Company, courtesy Leslie Salt Co.*

essing plant. The capacity of this belt conveyor system is 300 tons per hour.

Salt is delivered either to 300-ton stack-run storage bin or directly to four double-decked Tyler-Hummer vibrating screens that have a capacity of 200 tons per hour. Three sizes are produced, scalpings (plus three-quarter-inch) 101 (plus one-half-inch minus three-quarter-inch), and half-ground (minus one-half-inch). Screen analyses of these products are to be found elsewhere in this report. Scalpings and any excess of 101 are crushed with rolls and returned to the screens, and storage bins of 300 tons capacity are provided for the 101 and half-ground sizes. Cars and trucks may be bulk-loaded from any of the three 300-ton storage bins.

Alternatively salt from the storage bins may be sent to any of four sacking bins. Beneath each is a Richardson scale for sacking and a Union Special sewing machine for closing the sacks. The capacity of this equipment is 40 sacks per minute.

An additional size, 403, is made by crushing a portion of the half ground salt and is bulk-loaded only. The screen size of 403 is roughly plus 48 mesh minus 4 mesh.

The Ship-Loading Terminal. The ship-loading terminal at the Port of Redwood City is operated by the Leslie Salt Co.'s wholly owned subsidiary Leslie Terminal Company. The washer of the Redwood City crude salt plant is close by. The terminal was built to permit the direct loading of salt from stack to ship's hold by means of conveyor belts and save the rehandling costs in transferring salt to existing ocean terminals. Port of Redwood City was chosen because a deep w. channel existed there close to marsh land that the Leslie Salt Co. was bringing into production. Facilities include a channel 30 feet deep, a ship berth large enough for a Liberty or Victory-type ship, means for watering ships, and salt storage of 300,000 tons. Ships are loaded at a rate of over 600 tons per hour.

The construction of the terminal has been described by Allin (1948). At the site 21 feet of soft bay mud extends from plus 6 feet to minus 15 feet with respect to mean lower low water, and the extreme tidal range is 11 feet. Beneath the mud is 10 feet of stronger blue clay that in turn rests on an undetermined thickness of firm clay containing gravel lenses.

Three principal construction problems were involved: the building of 360 acres of crystallizing ponds in an area of peat-covered marsh cut by sloughs up to 8 feet deep, providing the foundation for a 300,000-ton stock pile of salt having an average load of $1\frac{1}{2}$ tons per square foot, and means for preventing the bank from sliding into the ship berth. The bank in the rear of the wharf would have to carry the weight of stacking and loading equipment, conveyor systems and other equipment, and rail and highway facilities in addition to a levee for protection against tidal incursions. A conventional structure consisting of a concrete deck supported by concrete-topped piling would have cost $2,800,000, more than the saving in ship-loading costs would justify.

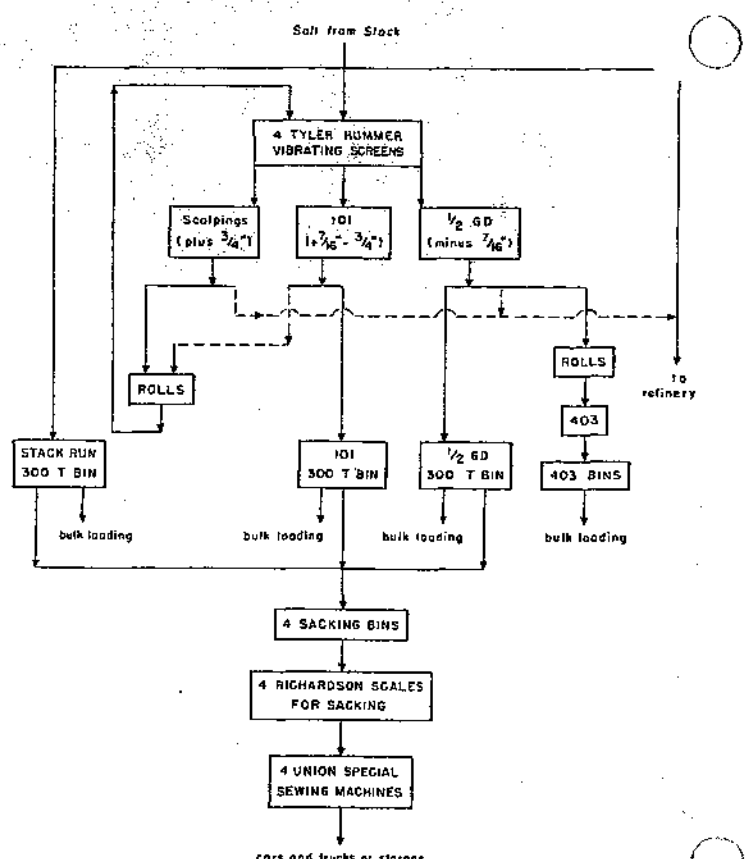

FIGURE 21. Undried salt processing plant, Leslie Salt Co. From processing plant flow chart 12-26-52 S/J.A.

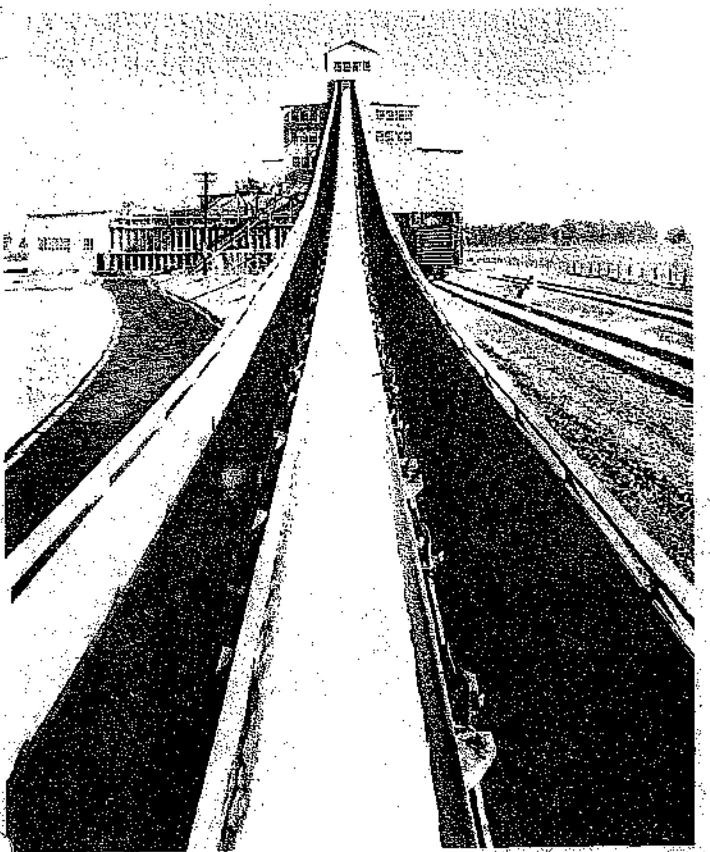

FIGURE 22. Undried salt processing plant, Leslie Salt Co., Newark. Salt is brought from the stock piles to the plant with a belt conveyor of 300 tons per hour capacity. Much of the salt is shipped in bulk without further treatment. Some stack run salt is processed into three screen sizes, and a portion is refined. *Photo by Herrington-Olson, courtesy Leslie Salt Co.*

To provide a foundation for the stack area the soft mud was pumped out of an area 726 feet by 680 feet and replaced with dredged sand; and to insulate the salt from the sand, the stack area was surfaced with two feet of clay. The foundation required 310,000 cubic yards of sand placed at a cost of $1.25 per cubic yard. Dredged shell costing $1.00 per cubic yard was considered, but compaction under load would have required an additional 46 percent if unbroken shell had been used or 31 percent for broken shell. The compaction of the sand was only one percent. The stack area was surrounded with a clay levee eight feet high and 80 feet wide at the base. It serves not only to keep out high tides, but also counterbalances the weight of the salt stack and prevents earth slippage.

For preparing the crystallizing area, 1,370,000 cubic yards of soft bay mud were pumped in, covering the peat and filling the sloughs to grade. Shell-free mud was required because any shell picked up with the salt during harvesting would not be removed in the washer. Part of the mud came from the salt stack area and the remainder from places in Redwood Creek and West Point Slough that test borings had shown to be shell-free.

The wharf area was stabilized by dredging the soft mud from a slot 90 feet wide parallel to the ship-berth and refilling it with stiff clay. The excavation of the ship-berth area furnished the clay required for this as well as for finishing the wharf site and for completing the salt-stack levee to full dimensions.

Salt is stacked with a belt stacker consisting of a short tower bearing an arm that projects upward and outward over the stack area. The stacker may be fed directly from the washer of the Redwood City crude salt plant or with salt brought in gondola cars from the east shore plants. The cars discharge through a rail grizzly to a hopper divided into seven sections. Each section contains a Barber-Greene loader that feeds to the stacking belt conveyor system. It is expected that the Redwood City plant will supply the greater part of the terminal's salt requirements when it is in full production. Alternatively salt may be brought from the east shore in the form of pickle from the Newark number one plant. A pipe line completed in 1951 crosses San Francisco Bay near Dumbarton Bridge and discharges into the Redwood City plant's pond system.

Salt is reclaimed from the stack by means of bulldozers and portable conveyor belts in a manner similar to that in use at Newark. It is also possible to draw salt directly from the washer or gondola cars. The main conveyor belt to the dock passes through a scale house with a weightometer to a central point on the dock. Here the flow divides and is sent to either of two towers. Each has an adjustable boom that can be lowered over the ship, and they can be rotated in order to reach the various holds without moving the ship. Each boom has a telescoping chute terminating in a short horizontal belt for spreading the salt within the ship's hold. All controls are centralized at a point above the dock from which there is a clear view of the entire operation.

Operations of the Western Salt Company

The principal producer of salt from sea water outside of the San Francisco Bay area is the Western Salt Company which has been in continuous operation on San Diego Bay for more than 80 years. David M. Miller is Vice President and General Manager, and N. B. Dittenhaver is Plant Superintendent. The main office is at 1245 National Avenue, San Diego.

The Western Salt Company's operations are centered in the comparatively small but efficient and modern plant at the south end of San Diego Bay near Chula Vista. A second, smaller sea water plant at Newport Bay, Orange County, is operated under lease, and the Western Salt Company is the sole owner of the Long Beach Salt Company with operations at Saltdale, Kern County.

The Chula Vista Plant *

The Chula Vista plant occupies 1600 acres of marsh land in sections 16, 17, 19, 20, and 21, T. 18 S., R. 2 W., S. B., around the south end of San Diego Bay. The plant office, washer, and mill are at Fruitdale station, approximately 2½ miles south of Chula Vista.

Average net evaporation in the Chula Vista area is 50 inches per year, and wind is a much less important factor than at San Francisco. The dissolved solids content of the bay water is about 3½ percent, approximately that of the open sea. Seasonal variations are slight, although 40 years ago substantial increases in salinity were observed in the summer months. The dredging of

* Plant visits April, September, 1953.